How Long and How Wide is the Lightning Channel?

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Let's begin with "how long". Channels longer than 90 miles have been observed (Ref. 10.1). On the other hand, sparks of a few yards length have been seen in and around clouds, and probably even shorter "lightning" exists.

There are basically four ways of determining channel length. (1) The most straightforward way is by photographing lightning and then determining its length from the photograph. Since channels inside clouds cannot be photographed, the value of this technique for determining channel length is somewhat restricted. (2) Radar has been used to measure channel length. A radar set sends out electromagnetic pulses which are reflected back by certain objects (e.g., metallic airplanes). Since the pulses

Figure 10.1: About 1,000 vertical yards of lightning channel near Tucson, Arizona (Ref. 10.4). Note the large scale channel tortuosity. (Courtesy H. B. Garrett and A. A. Few, Rice University)

travel at 186,000 miles per second, measuring the elapsed time between the emission of a pulse and the reception of its reflection enables the distance to the reflector to be measured. An actual radar set has a TV-like screen on which appears images of the reflecting objects. A lightning channel is a good conductor and hence reflects radar pulses much as an airplane does. Radar wavelengths can be chosen to minimize reflection of ra-

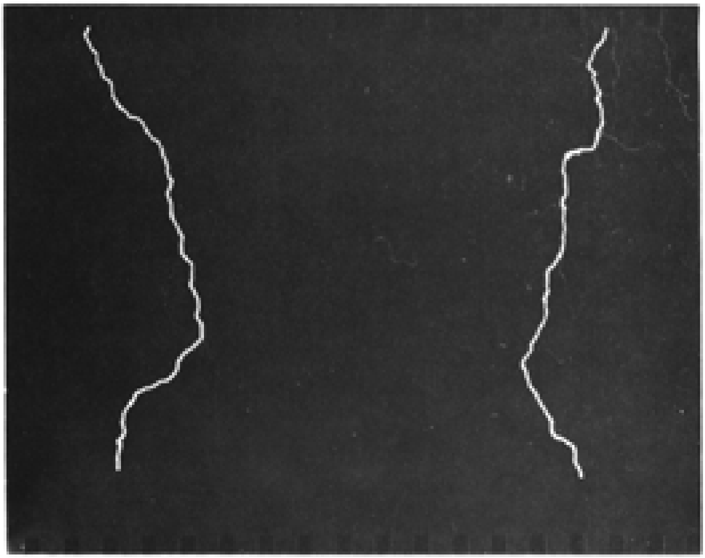

Figure 10.2: Bottom portion of the split channel shown in Figure 10.1 (Ref. 10.4). Vertical height shown is about 200 yards. Tortuosity on a scale smaller than 10 yards is evident. (Courtesy, Leon E. Salanave, University of Arizona)

dar pulses by the ice and water in clouds so that a good image of the lightning channel can be obtained on the radar screen. (3) Channel lengths can be determined from the duration of thunder. The minimum possible channel length associated with a thunder duration of T seconds is roughly T/5 miles (see Chapter 12). For example, if thunder lasts 20 seconds, the channel producing it has a length of about 4 miles or more. (4) Finally, there are a number of ways of determining lightning channel height within a cloud from electrical measurements made on the ground (Ref. 10.2). Charge motion in the lightning channel or in the cloud will induce voltages and currents in ground-based instruments enabling properties of the channel and cloud charge to be determined. For example, the vertical height of the J-streamers and K-streamers occurring in the cloud between strokes (Fig. 9.3) can be determined from electrical measurements made at ground.

Now that we know how channel lengths are measured, let's look at the results of the measurements. The average vertical

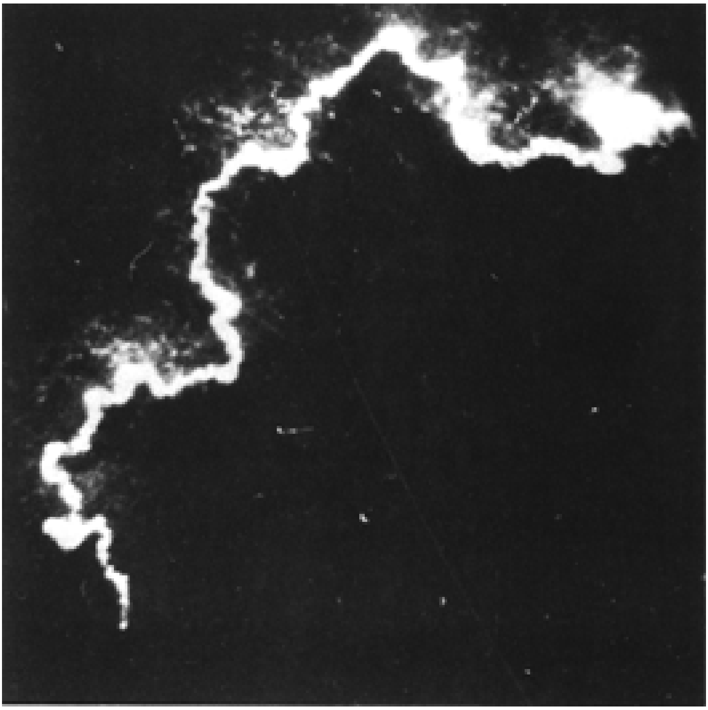

Figure 10.3: One frame from a high-speed movie of lightning striking a TV tower near Tucson, Arizona (Ref. 10.5). About 10 yards of channel are shown and tortuosity on an inch scale is evident. (Courtesy, W. H. Evans, University of Arizona, and R. L. Walker, University of Florida, Cape Canaveral)

stroke height is about 3 to 4 miles. The maximum vertical extent of the usual stroke to ground is the top of the N-charge region, a height of 6 miles or more. Each stroke in a multiple-stroke flash averages about a third of a mile longer than the preceding one. This is the case because, in order to obtain negative charge for a new stroke, J-streamers and K-streamers tap new areas of the N-charge region of the cloud (Figs. 8.3 and 9.3) during the time between strokes, and these tapped regions become part of the new stroke. The horizontal component of the lightning channel within a cloud or through several clouds may be larger than the vertical component. Horizontal sections of 5 to 10 miles within clouds are not uncommon. Radar studies have shown horizontal channels longer than 90 miles (Ref. 10.1). Long horizontal channels must feed on the charge of many thundercloud cells. In addition to cloud-to-ground discharges with long horizontal in-cloud components or similar long intracloud or cloud-to-cloud discharges which do not reach ground, long lightning discharges have occasionally been observed to occur from the tops of thunderclouds upward (Ref. 10.2). These vertical air discharges may be tens of miles in length.

When we speak of the length of lightning, we normally picture long sections of the channel as being fairly straight. Photographs show, however, that the channel is very tortuous on almost any scale. There are zigs and zags 100 yards long and, within these, other zigs and zags 10 yards long, and within these yet smaller zigs and zags (Refs. 10.3, 10.4, 10.5). Very detailed photographs have shown lightning channels that twist and bend on a distance scale measured in inches (Ref. 10.5). Figure 10.1 shows a section of a lightning channel with a height of about 1000 yards; Fig. 10.2 shows about 200 yards of channel; Fig. 10.3 about 10 yards. If we could grab a long section of the channel and pull on both ends to straighten it out, the channel section might well be two or more times longer than we initially thought.

Lightning diameter measurements have been made in two ways: (1) by examining the interaction between lightning and objects and (2) from photographs. Photographic measurements of lightning almost always overestimate the luminous diameter of the channel: the bright channel overexposes the film making the recorded image broader than it should be. It is extremely difficult to expose a lightning channel photograph properly. The best channel diameter photographs (Ref. 10.5) yield diameters of between about 2 and 7 in., and these values are probably overestimates. Lightning photography is discussed again at the end of this chapter.

When lightning hits an object such as a tree or a rock, it leaves visible damage. In many cases the damage can be related to channel diameter. Taylor (Ref. 10.6; see also Chapter 5) found that the lightning-caused furrows that spiral along tree trunks are between about 0.6 and 5.0 in. wide. The lightning diameter, therefore, must be roughly this size or smaller. If it were much bigger, it is hard to see how it could create the furrows.

When lightning strikes sand or certain kinds of rocks, the channel heat melts the material along its path. When the melted material solidifies, the resulting fulgurite (from the Latin fulgur, meaning lightning) represents a permanent record of the lightning diameter and path. Fulgurites in dry sand are generally long hollow tubes with corrugated glassy walls. An artificial fulgurite produced by an electrical discharge in the laboratory is shown in Fig. 10.4. Fulgurites have been traced downwards into sand as much as 20 yards. Diameters are usually 0.5 to 2 in. From the corrugated appearance of fulgurite walls, it is probable that the initial diameter collapses somewhat on cooling. "Fossil" fulgurites 250 million years old have been discovered (Ref. 10.7). The fulgurite diameter probably does not differ much from the lightning diameter.

The author has measured lightning diameters by allowing lightning to pass through Fiberglass screens on the way to lightning rods and then measuring the size of the holes melted in the screen by the lightning (Ref. 10.8). The screens covered rods on the tops of towers near Tucson, Arizona and near Lugano, Switzerland. About 50 holes were obtained. Figure 10.5 shows typical lightning holes. Diameters were usually about an inch or smaller and sometimes were as small as a sixteenth of an inch. Hole diameters represent the width over which the lightning channel is hot enough for sufficient time to melt or vaporize the screen.

When lightning strikes an electrical conductor such as a lightning rod or an airplane wing, it often leaves a spot (sometimes a raised lump, sometimes a depression) about an eighth of an inch wide. Examples of such spots on three copper disks are shown in Fig. 10.6. The size of a lightning spot is roughly the diameter of the lightning channel when it enters the conductor. At the contact point the lightning current must flow through a mixture of metal vapor and air, with the result that its diameter is smaller than in the metal-free air away from the conductor. Thus, spot sizes on conductors provide a lower diameter limit. It should be noted that a large lightning cur-

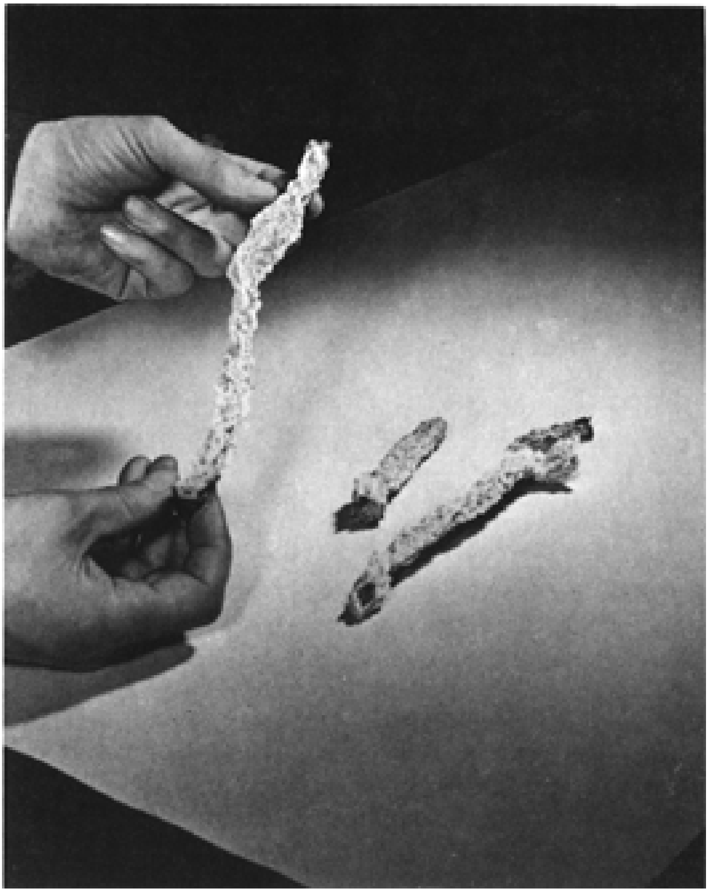

Figure 10.4: Artificial fulgurites produced by P. L. Bellaschi, Westing house Electric Corporation, by allowing an electrical discharge to pass through quartz sand. The hollow tubes of solidified sand are close replicas of natural fulgurites.

rent flowing for a relatively long time may do considerably more damage to a conductor than just a spot. A hole may be burned (Figs. 4.1-4.3) or the conductor may be totally melted or vaporized.

Based on all the available evidence, the lightning channel diameter is of the order of an inch. However, for two reasons there is some ambiguity concerning what is meant by lightning diameter. First, there is no definite boundary between the stroke

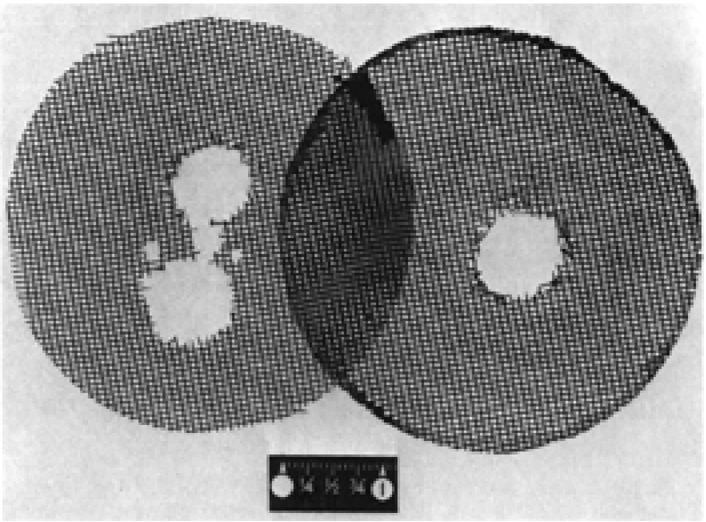

Figure 10.5: Holes melted in two Fiberglas screens by lightning. At least four strokes passed through the screen on the left. One stroke passed through the screen on the right.

and the air surrounding the stroke; second, the diameter must change with time in response to the changing current.

Why is the lightning channel so tortuous? The answer is not known, but some reasonable guesses may be made. The larger-scale tortuosity in the channel (representing, say, tens of yards or more) is due to the fact that the stepped leader makes such an errant trip to ground. Why does it do this? Possibly various airborne regions of charge (space charge, see Chapter 6) divert the leader on its trip. More likely, the leader just doesn't know exactly where it wants to go, except that ultimately it wants to move downward. The smaller scale tortuosity in the channel may be formed when the leader steps are formed, or may be formed by action of the magnetic forces associated with the return stroke current. As is probably becoming more and more apparent with each succeeding chapter in this book, there is an awful lot we still don't know about lightning.

Since we have discussed in this chapter the use of photography as a scientific tool to determine lightning channel parameters, it is appropriate to say a few words about how to take lightning

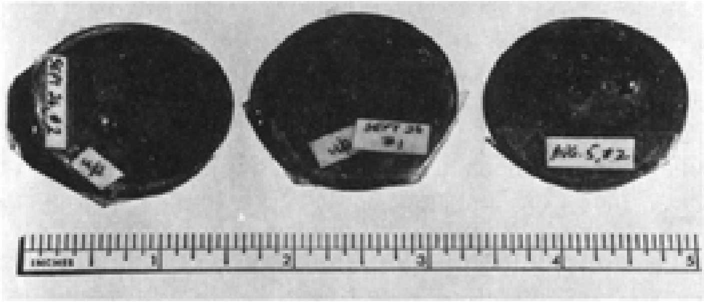

Fig 10.6. Spots produced by lightning strikes to three copper disks which were placed on top of TV towers near Tucson, Arizona. The center disk was apparently hit by three lightning strokes, one of which raised a one-eighth inch lump. The disk on the right exhibits a copper lump apparently formed as the lightning channel moved back and forth across the disk.

photographs. There are basically two ways to photograph lightning using ordinary cameras with no special attachments: (1) by time exposure until the lightning occurs and is over, and (2) by snapping the camera shutter (set at 1/30 sec or slower) when the lightning is first seen.

(1) The camera is put on a tripod or other firm base, pointed in the direction of the storm, and the shutter is left open (time exposure) until lightning occurs in the field of view. Of course, it must be nighttime, otherwise the film will be immediately fogged. The length of time the shutter can remain open without appreciable fogging of the film depends on the ambient light level. Away from city lights with a film speed of ASA-I00 (roughly the speed of Kodak Plus-X black and white film or Kodacolor-X color film) and an aperture opening of f/11, several minutes are possible. Camera focus should be set at infinity. Since there are several lightning strokes to ground during each minute of the electrically active period of a storm (Chapter 7), it is not difficult to obtain photographs. (2) If the lightning flash to be photographed consists of only one stroke, your reflexes will not be fast enough to fire the shutter in time to record the flash. However, if it is a multiple-stroke flash, as most flashes are, you will record a subsequent stroke or strokes. Since subsequent strokes occur at intervals of roughly 1/30 of a second, a shutter speed of 1/30 second or slower is necessary to

avoid taking a picture of what goes on between strokes. Since subsequent strokes are generally unbranched (Chapter 9), the photographed lightning will be unbranched and will look somewhat peculiar. Again, for a film speed of ASA-100 try an aperture of f/11 with the focus set at infinity.

The two basic techniques for photographing lightning can be improved by using special equipment with ordinary cameras. (1) Time exposures of lightning in daylight are possible if the proper filter is used (Refs. 10.9, 10.10). Light from the sun is weak at a wavelength of 6563Å* (in the red) because hydrogen in the sun's outer layers absorbs that wavelength, the so-called Hcx line. Hydrogen is present in the lightning channel due to the high-temperature break-up of water vapor (H_2O). Since hydrogen in the lightning channel radiates at 6563 Å (H_α) (see Chapter 11), it follows that an H_α filter that passes only light near this wavelength both allows the channel to be photographed and prevents rapid film fogging by daylight. For maximum effectiveness, the film used should have good red sensitivity. Kodak Linagraph Shellburst is perhaps the best for the purpose. In cloudy weather at f/11, a daytime exposure of several minutes should be possible without excessive film fogging. A 2x2 in. Hcx filter with a bandwidth of about 40 Å costs about $200. (2) Triggering the camera shutter can be accomplished with instruments that respond to the electrical signals generated in the cloud or by the stepped leader prior to the first return stroke (Refs. 10.11, 10.12). In this way the first stroke can be photographed. Essentially, the shutter is tripped by a solenoid coupled to a radio antenna and appropriate electronics.

*One Å (Ångstrom) equals one ten-billionth of a centimeter. There are 2.54 centimeters to the inch.

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THE EVENT

Petrified Lightning from Central Florida

a Project by Allan McCollum

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